Condensation of Vapors on a Horizontal Tube

Temperature Variation around the Perimeter of a Tube on Condensing Pure and Mixed Vapors

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Condensation of Vapors on a Horizontal Tube[1]

Temperature Variation around the Perimeter of a Tube on Condensing Pure and Mixed Vapors

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A suitable method is described for measuring temperature variation around the perimeter of a horizontal tube on which vapor is condensing. It is found that the variation is relatively small with small temperature differences between tube wall and vapor, but the variation is large with moderate and large temperature differences. The data obtained in this investigation indicate that there is no point around the perimeter where a thermocouple junction may be located so that it may be depended upon to give the correct mean tube temperature and correct heat transfer coefficients. Measurements were made with water and benzene alone, and with the mixed vapors water-benzene, water-toluene, water-mixed heptanes, and water-trichloroethylene.

IN MOST heat transfer measurements made on horizontal tubes the possibility of temperature variation around the tube has been neglected. Since Nusselt (*12*) had derived an equation showing the variation of film thickness around the perimeter of the tube and presented it at the same time as his equation for the condensation of pure vapors, it is surprising that most workers making measurements of heat transfer coefficients have not taken into account the effect of this variation on the temperature drop. Langen (*7*) presented some measurements of the temperature variation around the perimeter of the tube. However, the method of measuring the temperature of the tube with resistance thermometers along the tube at various points around the perimeter does not give the true temperature variation around the perimeter, but instead gives the average temperature along the tube at one point of the perimeter plotted against the various positions on the perimeter.

The purpose of this paper is to describe a suitable method of measuring temperature variation around the perimeter of a horizontal tube, to present data so obtained, and to show the importance of correctly taking into account this temperature variation.

Apparatus

The apparatus (described on page 1067) was essentially a single horizontal copper tube enclosed in a jacket, with cooling water flowing through the tube and vapors condensing on the outside. Thermocouples in the vapor space and embedded in the tube wall served to measure temperatures. The tube could be turned about its axis at will, thus rotating about the tube the points at which tube wall temperatures were measured. Means were provided for regulating the temperature of the cooling water and the rate at which it flowed through the tube. The vapors studied were generated in a still.

Results

Nusselt (*12*) developed an equation showing the variation of film thickness around a horizontal tube from a theoretical standpoint. Since for constant values of h the thickness of the film determines the temperature drop and is directly proportional to it, the variation of the temperature around the tube is also an indication of the variation of the film thickness around the tube.

The condensation of the mixed vapors, however, presents the combined drop and film condensation and complicates the analysis of the temperature drops around the tube. The temperature read at any point on the perimeter depends upon whether the thermocouple junction is beneath a drop or the film. Since the drop has a diameter considerably larger than the thickness of the film, it can readily be seen that when a drop passes over the thermocouple the temperature indicated will change considerably. This was evidenced in the experiments by wide fluctuations of the thermocouple readings. At the lower rates of condensation there were practically no fluctuations of the thermocouple temperatures and by observation there were fewer drops flowing over the junctions. The drops seemed to be principally of a uniform size around the tube, though occasionally some slight differences could be noticed. The effect of the temperature variation with low temperature drops was to show the variation of film thickness around the perimeter, since the only effect of the drops was to cause a sudden change of temperature which existed only over a short distance on the perimeter without affecting the general trend of the temperature variation around the tube.

The variation of temperature around the tube at high and at low rates of condensation is shown in Figures 1 and 2 for pure water and for pure benzene. Figures 3 to 6 show the

[1] Complete tables of data obtained in these experiments will be found in the *Transactions of American Institute of Chemical Engineers.*

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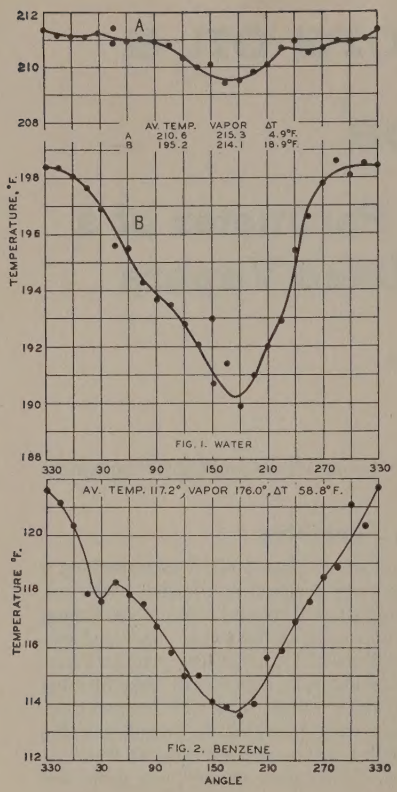
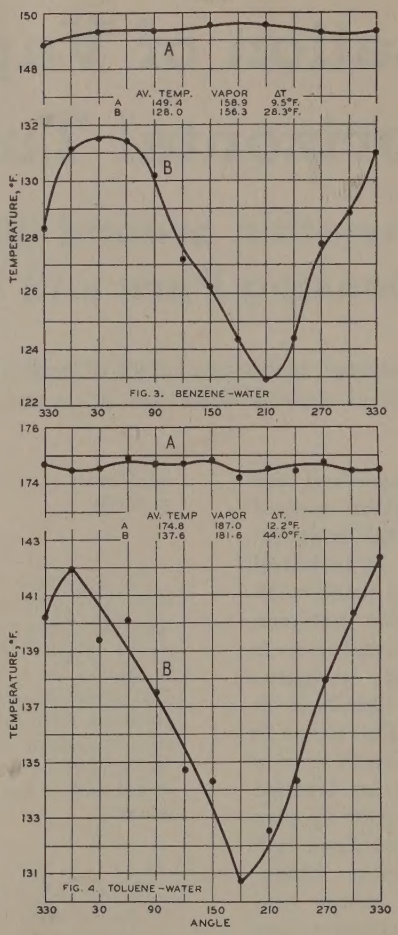
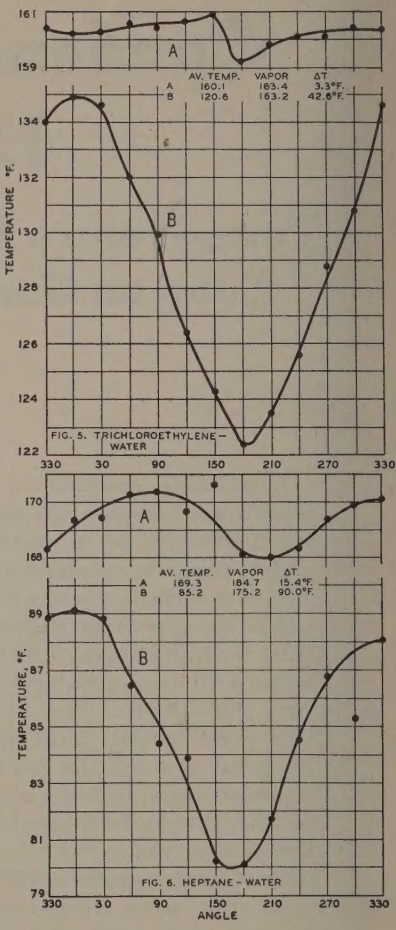






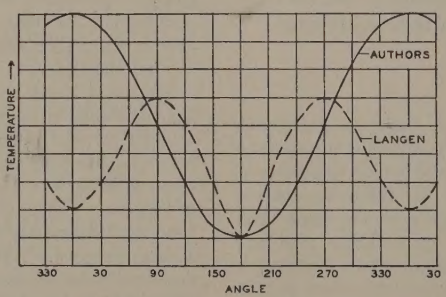


FIGURE 7. QUALITATIVE COMPARISON OF LANGEN'S DATA WITH THOSE OF THE AUTHORS

variation at high and low rates of condensation for the mixtures benzene-water, toluene-water, trichloroethylene-water, and heptane-water, respectively. The top of the tube is at the angle of 0°, and the bottom is at 180°. The film is thinnest at the top and thickest at the bottom of the tube.

Langen (*7*) measured the wall temperatures by burying resistance thermometers lengthwise of the tube. By using eight of these thermometers equally spaced on the perimeter of the tube, the temperature variation was measured. Langen's method of measuring the temperature variation gives the average temperature along the tube at several points on the perimeter; the method used in the present work gave actual temperature variations around the tube at one point along the tube.

Langen found that the temperature at the top of the tube was the same as that at the bottom, and that the maximum was at the middle. In practically all of the present experiments the type of temperature variation was the same as shown in Figures 1 to 6. A comparison of the results obtained by Langen and by the writers is shown in Figure 7. It is apparent that the present results are more in agreement qualitatively with those predicted from the Nusselt equation, whereas Langen's results indicate a thick film on the top as well as on the bottom of the tube.

The differences between the maximum and minimum temperatures around the tube divided by the average temperature drop were plotted against the average temperature drop for the several systems. These plots show that the points spatter widely, and that there is no consistent relationship that can be mathematically formulated. Apparently the average temperature must be experimentally determined in each case, and the use of a single thermocouple in a stationary tube may result in considerable error in measuring the tube wall temperature.

Conclusions

Any error in the measurement of the mean tube temperature necessarily causes a corresponding error in the determination of the coefficient. In the past this temperature variation has been neglected and therefore has probably caused errors in the calculation of coefficients for horizontal tubes.

The assumption that the position of the thermocouple halfway between the top and bottom will give the average temperature is erroneous since the film thickness is continually increasing towards the bottom of the tube, and the average

film thickness is not at the 90° or 270° angle, 0° being the top of the tube. The position on the perimeter that seems to give the least error for a single measurement lies somewhere in the lower quadrants. This is also shown to be true by Nusselt in his derivation of the equation and illustrative example (*12*). However, data taken in this research show that there is no location for the thermocouple that can be depended upon to give correct average readings for the tube temperature.

The variation of the temperature around the tube is very important and cannot be neglected in the calculation or determination of coefficients of heat transfer on horizontal tubes. No previous work has been published on the variation of temperature around the tube at some particular position along the tube, although Langen has published data on the variation around the tube of the average temperature along the tube.

Further refinements in the measurements of temperature of a single point on the tube wall are useless unless the larger error of temperature variation around the tube is corrected. It is possible to overcome the difficulty of temperature variation and to obtain the average surface temperature from the electrical resistance of the tube, as described by Jeffrey (*4*). However, the objections to this system of measurement are that the tube is of low electrical resistance so that extremely accurate and expensive instruments are required.

Heat Transfer Coefficients for the Condensation of Mixed Vapors of Immiscible Liquids

Coefficients of heat transfer from vapor to a horizontal tube were determined for the condensation of mixed vapors of immiscible liquids. These coefficients were based on true tube wall temperatures determined by temperature measurements around the perimeter of the tube. The mixed vapors studied were those of water with benzene, toluene, mixed heptanes, and trichloroethylene, respectively. These data, and also those of Kirkbride, were correlated in the empirical equation:

$$h\left(\frac{\mu^2}{k^3_{\text{av.}}\,\rho^2_{\text{av.}}\,g}\right)^{1/3} = 1.28\left(\frac{C_{p\text{av.}}\,\mu\,\rho^{0.7}_{\text{av.}}}{k_{\text{av.}}\,\lambda_{\text{av.}}}\right)^{2.38}\left(\frac{Q_s}{Q}\right)^{-3.28}$$

The film coefficient, h, is independent of ΔT. The type of condensation obtained is described as film dropwise.

ALTHOUGH steam distillation and stripping processes have been practiced for many years, the design of condensers for these processes has been mostly by rule-of-thumb procedure. These processes are becoming more important and have not been given the attention they deserve.

The purpose of this investigation was to find some method of predicting the coefficient of heat transfer on the vapor side of condensers. Since heat transfer coefficients for the cooling medium side of condensers can, in most cases, be calculated, knowledge of the coefficient for the condensation of mixed vapors of immiscible liquids would permit calculation of the over-all coefficient of heat transfer and the size of the condenser.

Very little work has been done on coefficients of heat transfer for the condensation of mixed vapors of immiscible liquids. Kirkbride (*6*) presented some data and proposed an equation. However, he had not varied either the temperature drop or the composition of the vapors sufficiently to determine their effect on the coefficients. The vapors entering his condenser were not in the equilibrium proportions, but consisted principally of benzene or naphtha with only small proportions of water.

Apparatus and Experimental Technic

The apparatus was essentially a single horizontal copper tube enclosed in a jacket, with cooling water flowing through the tube and mixed vapors condensing on the outside. Means were provided for regulating the temperature of the cooling water and the rate at which it flowed through the tube. Mixed vapors of the liquids were generated in a still. In some experiments these vapors passed directly into the jacket whereas in others they were passed through a partial condenser so as to produce equilibrium vapors.

Considerable difficulty was experienced in obtaining equilibrium vapors from the still. The nonequilibrium vapors were probably the result of insufficient agitation in the still and the separate formation of the vapors of each liquid from different parts of the heating surface. The first attempt to remedy this situation was to install a spray nozzle in the vapor line and to pump the liquid from the bottom of the still through the spray nozzle. However, this method was not satisfactory, and a large partial condenser was placed between the still and the condenser tube. A small quantity of cooling water flowing through the partial condenser ensured the condensation of some vapor. The mixed vapors passing over both liquid phases, which were spread over a large area, gave equilibrium conditions.

Details of the apparatus are shown in Figures 1 and 2: The copper tube on which the condensation occurred had a nominal outside diameter of 1.314 inches and an inside diameter of 0.951 inch, and was 6 feet long. (These are the dimensions of standard 1-inch extra heavy iron pipe.) This pipe or tube passed through the center of a 4.5-foot length of an 8-inch iron pipe which served as a jacket. The jacket, which was well insulated, had a packing gland at each end through which the copper tube passed, permitting rotation of the tube. Three sight glasses, installed in the jacket, were valuable in permitting the constant observation of the formation of condensate on the tube.

The area of tube from which condensate was collected was limited to 44 inches of the total length by fins placed around the tube. Below the tube was a trough 44 inches long and 1.5 inches wide which collected the condensate dripping from the measured length of the tube. To prevent the condensate from flowing to or from the measured length of tube in case it was not perfectly level, fins were placed around the tube. These were made of canvas, impregnated with a Bakelite varnish, and therefore had practically no effect in increasing the condensation area. By using only a portion of the tube length in the jacket, the possibilities of end effects where the tube came into contact with the jacket were eliminated.

Installation and Calibration of Thermocouples

All thermocouples were of the copper-constantan type with silver-soldered junctions. The potentiometer for taking the readings was a Leeds & Northrup portable precision type, limiting the accuracy of the temperature readings to ±0.1° F.

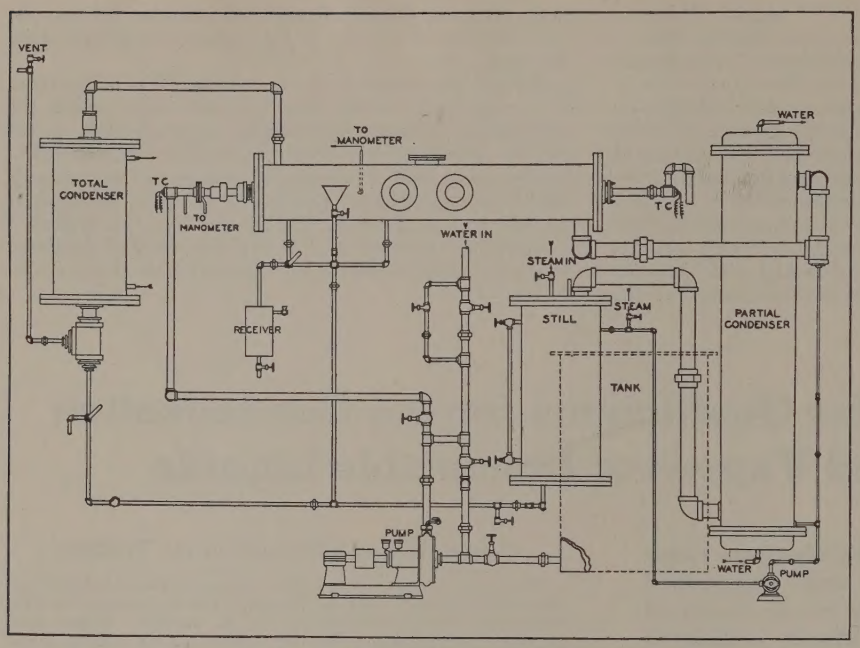


FIGURE 1. ARRANGEMENT OF EQUIPMENT

The vapor and water thermocouples were sealed in 1/8-inch pipe with Bakelite varnish. The junctions were exposed to the vapors of water. The vapor thermocouples extended into the jacket at the same level and within 2 inches of the condensing tube, and were placed at each end of the measured condensation length. The water thermocouples extended inside the tube to the limits of the measured length of the condensing section.

The vapor and water thermocouples were calibrated in an oil bath, held at a constant temperature to within 0.01° F. by comparison with a standard platinum resistance thermometer. During the calibration thermocouple readings were taken with a Leeds & Northrup type K-2 precision potentiometer, and resistance measurements were made with a Mueller bridge.

Six thermocouples were placed in the wall of the tube, the first and last thermocouples being 1.1 inches from the limits of the condensation length. The distance between one pair of thermocouples was 9.75 inches, and the distance between the remaining thermocouples was 8.00 inches. The tube thermocouples were calibrated twice; first a preliminary calibration was made before installing the thermocouples into the tube to permit the detection of any faulty thermocouple before proceeding further. This calibration was made by placing the thermocouples and the standard resistance thermometer in a vapor space over liquids of different boiling points. The thermocouples were again calibrated after the tube and thermocouples were in place. This time the thermocouples were read with the portable precision potentiometer and calibrated against the vapor thermocouples. It was found that the calibration had changed somewhat during the installation, and the latter calibration was used in all calculations.

The method of installing the tube thermocouples is shown in Figure 2. A groove 3/32 × 3/32 inches was cut three-quarters around the tube and then at an angle of 30° for 1/2 inch. At the end of this angular groove, a 1/16-inch hole, approximately 1/4 inch long was drilled. By this method of installation the thermocouple junctions were underneath a copper surface and, regardless of the position of the junction on the perimeter of the tube, no condensate flowing over the junction could be affected by the groove. The lead wires came out of the groove to one side and three-quarters of the circumference of the tube away from the junction.

Many methods of sealing the lead wires into the groove were tried. Pure Bakelite varnish plus a filler had a tendency to shrink and crack in service. Litharge and glycerol cement disintegrated. Litharge and glycerol cement with a covering of the Bakelite varnish also failed.

The method that was finally adopted and that proved successful was to enclose the lead wires in a small brass tube about 0.08 inch o. d. and 0.05 inch i. d. The leads inside the brass tube were the regular enameled, silk-covered thermocouple wire. In addition to this insulation, a thin coat of resin was applied and baked on over the silk covering. The junction was soldered into the hole at the end of the groove. The brass tube was pushed over the leads until it butted up against the end of the groove and then bent to fit the groove and carefully soldered in place. The solder was polished until flush with the surface of the copper tube.

It was necessary that the brass tubes enclosing the thermocouples be brought out of the jacket in some manner that would not interfere with the rotation of the copper tube through a 360° angle. They were, therefore, laid along the copper tube near one end of the latter. A brass collar, about 4 inches long, 1.47 inches i. d., and 1.66 inches o. d., was slipped over the brass tubes, and the spaces between the collar, the brass tubes, and the copper tube were closed with solder. The packing gland bore on the brass collar, thus making a tight joint without interfering with the desired rotation of the copper tube–thermocouple assembly.

Experimental Procedure

The surface of the tube was oxidized with either steam or mixed vapors before taking data. With this type of surface the film coefficients on the same mixtures could be checked, even though several months had elapsed between tests. This type of surface can, therefore, be considered as having constant surface characteristics. Also, this is the type of surface that is usually obtained in practice.

In order to sweep noncondensable gases from the jacket where the rate of heat transfer was being studied, a secondary or total condenser was provided, and vapors were passed from the jacket into this condenser. Several tests were made to determine the efficiency of the venting and whether it would be possible to eliminate all of the noncondensable gases. These tests were made by introducing air into the still and determining the time required for the vapor thermocouples to return to the original temperature. About 10 seconds were necessary for the air to travel from the first to the second vapor thermocouple. About 30 to 60 seconds were required for the second thermocouple to return to its original reading.

The elapsed time, after starting up the equipment before taking readings for a run, was at least 30 minutes and was, therefore, sufficient to eliminate all traces of noncondensable gases.

A run consisted of taking the vapor, water, and tube thermocouple readings and then the manometer readings, one on the water rate and the other on the pressure in the jacket. The tube was then rotated 30° and all readings were repeated. This was continued until the tube had been rotated 360° when the run was considered complete. There was, therefore, no definite length of time to make a run, but the average time was between 30 and 40 minutes.

Samples of the condensate from the measured length of the tube were taken from the collecting trough, weighed, and analyzed. The practice was to take four sets of samples during a run; a sample was taken after every third rotation (90°) of the tube. The sample was collected over a short interval (30 seconds to 2 minutes) by throwing the three-way stopcock so that the liquid from the trough passed into the receiver.

The analysis of the condensate was simple. Since the liquids were immiscible, they were separated with a separatory funnel and the components weighed. From the analysis of the samples, the quantity of each component condensing per hour was calculated. The total quantity of heat is then the sum of the weight of each component condensing per hour multiplied by the latent heat of vaporization of each component at the temperature at which the condensation was taking place. This is justifiable since the condensing vapors under these conditions can be assumed to be present in proportion to the relative amounts of these substances in the condensate collected. The only other assumption involved is that the liquids are sufficiently immiscible so that the heats of solution are negligible. The total heat of condensation of the mixture is then the sum of the individual latent heats multiplied by the net weights of the respective components in the collected condensate.

Since there was a temperature variation around the tube, the average temperature at each thermocouple position along the tube had to be determined. To determine the average temperature around the tube, the potentiometer readings, in millivolts, were plotted against the angular position of the thermocouple. The resulting curve was integrated with a polar planimeter. Dividing the area under the curve by the abscissa of the curve gave a properly weighted average or mean millivolt reading. Millivolts were thus averaged instead of actual temperatures, because over the range of temperature variations around the tube the calibration curve converting millivolts to temperatures is a straight line. The error, if any, in this assumption is well within the accuracy of the calibration.

The temperature drop through the film was determined by plotting the corrected or mean temperature drop at the various thermocouple positions on the tube against the length or distance between the thermocouples. This curve was also integrated with a polar planimeter, and a mean temperature drop was obtained.

Since the thermocouples were under some metal, a correction might have been made for the temperature drop through this thickness of metal. However, no such correction was made since the largest possible error was of the order of 2 to 3 per cent of the total corrected temperature drop through the film.

Results

Four systems were studied; water was one component in all the systems. The other components, respectively, were benzene, toluene, mixed heptanes, and trichloroethylene. Measurements were also made on water alone and benzene alone. Both benzene and toluene were technical grade materials. The mixed heptanes probably contained all the isomers of heptane. The trichloroethylene was obtained by redistillation of a commercial degreasing solvent; both the specific gravity and the boiling point closely approximated that of pure trichloroethylene.

When condensing pure vapors, film-type condensation was obtained. However, the condensation of the mixed vapors gave a type of condensation in which both drops and film were present, as shown in the photographs taken through the sight glasses (Figure 3) and described by Cogan (*2*). In most cases drops of one liquid formed on the tube and the film of the other liquid ran over those portions of the tube not covered by the drops themselves and over the drops at the bottom of the tube. Analysis of the condensate showed that the quantity of water condensate which formed was smaller than the quantity of nonaqueous condensate. By observation of the quantity of condensate coming from the tube in the form of the drops and in the form of the film, it was apparent that the drops produced the smaller quantity of condensate, thus confirming the supposition that the drops were water and that the film was the nonaqueous liquid.

The appearance of the condensation was that the drops were fairly stable, remained on the tube for considerable lengths of time, and covered the greater portion of the tube (Figure 3). The drops were of considerable size, averaging about 1/8 inch in diameter; occasionally some of the drops at the top of the tube were approximately 3/8 to 1/2 inch in

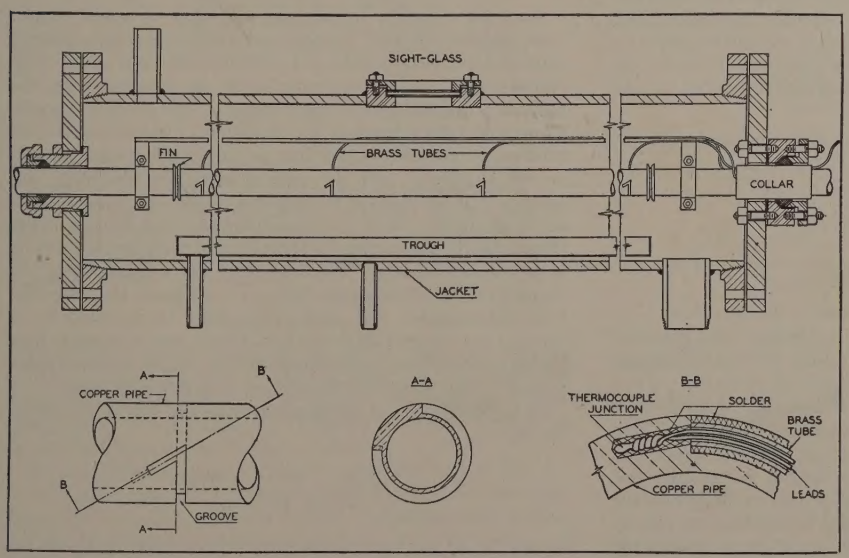


FIGURE 2. DETAILS OF TUBE AND METHOD OF INSTALLING THERMOCOUPLES

diameter. The film was in direct contact with the drops, and at the bottom of the tube the film covered the drops. Occasionally small drops could be seen floating on the film.

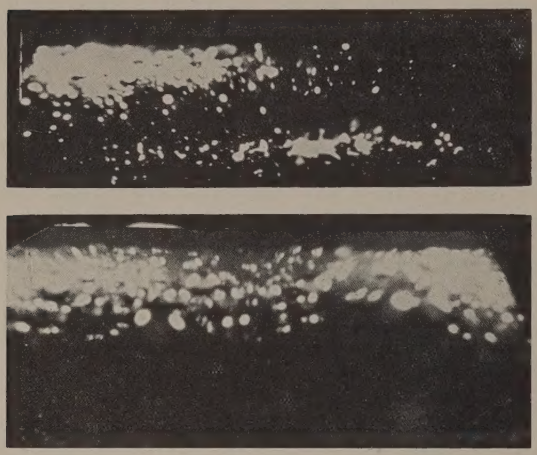


FIGURE 3. PHOTOGRAPHS TAKEN THROUGH SIGHT GLASSES, SHOWING FILM-DROPWISE CONDENSATION

The rate of heat transfer through a condensate film can be expressed by the equation

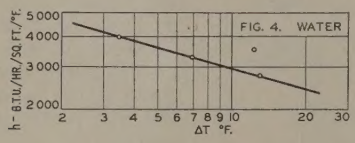
$$Q/\theta = hA\,\Delta T$$

where Q/θ = heat transferred, B. t. u./hr.
A = area of heat transfer surface, sq. ft.
h = film heat transfer coefficient, B. t. u./(hr.)(° F.)(sq. ft.)

Since all the terms except h are obtained from the data, h can be calculated.

The following data were obtained from McAdams (*8*): specific heats of water, benzene, toluene, heptane, and trichloroethylene; thermal conductivity of water, benzene, toluene, and heptane; latent heats of vaporization of benzene and heptane.

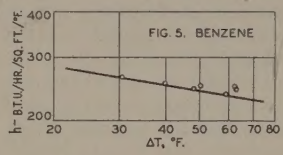
The thermal conductivity of trichloroethylene could not be found in the literature and was therefore calculated from the empirical formulas of Weber and of Smith as given by McAdams (*8*). The value calculated from each formula was the same, and this value was then used throughout all the calculations.



The literature also included the following data: densities of all materials (*3*), and the latent heat of vaporization of trichloroethylene (*1*), of toluene (*10*), and of water (*5*).

Figures 4 to 9 show the effect of temperature drop through the film on the observed coefficients of heat transfer. These graphs show that, except for the single systems water and benzene, the mixed heptanes-water system is the only one that shows any material dependence of the coefficient on the temperature drop for the condensation of equilibrium vapors.

The first attempt to formulate an equation to predict the coefficients was to split the total coefficient into individual coefficients for each component. However, this was not successful, although a plot of the logarithm of the water coefficient h_w, against the logarithm of the ratio of the quantity of heat transferred by the water component to the total quantity of heat transferred, Q_w/Q, gave a curve which when extrapolated may line up with the coefficient for the dropwise



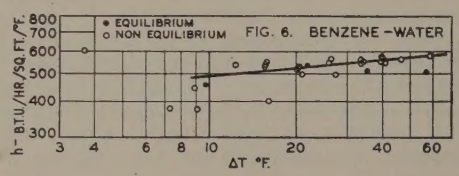
condensation of pure steam as reported by Nagle, Bays, Blenderman, and Drew (*9*). These authors showed that in the dropwise condensation of steam the coefficient is independent of the temperature drop. This is likewise true of the condensation of the mixed vapors of water with benzene, toluene, and trichloroethylene.

Kirkbride (*6*) presented the equation

$$h = \frac{h_w Q_w + h_s Q_s}{Q_s + Q_w}$$

where the individual film coefficients were determined by the Nusselt equation (*11*, *12*).

Kirkbride's equation is based on the Nusselt equation in which the calculated coefficient is dependent on the temperature drop through the film, but the coefficients observed were independent of the temperature drop; therefore any modification or method of weighting the Nusselt equation must be fundamentally in error.

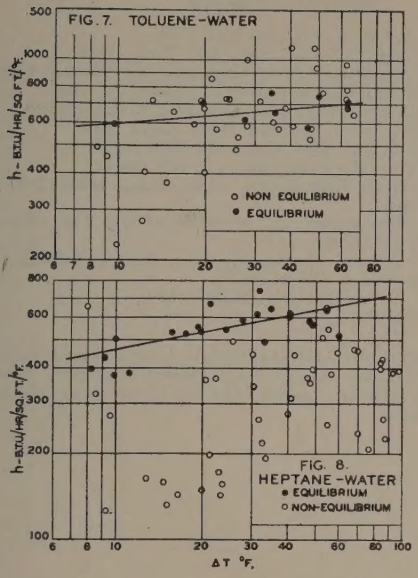


Since an equation for the condensation of mixed vapors must involve a layer of liquids on the tube and as the equation derived was based on the total coefficient and not on the individual coefficients, some means had to be used to weight the various properties of the components. The density, specific heats, and latent heats of vaporization of the mixed liquids were easily calculated according to the weight of each present in the mixture. The average thermal conductivity was weighted on the basis of the volume of each component present in the liquid phase, on the assumption that the quantities of each liquid present on the tube were in the same proportion as in the condensate. Viscosity was not weighted, but the viscosity of the component forming the film in the drop-film type condensation was used. This may be assumed to be correct since it was only the film which was in regular flow on the tube surface, as the drops stayed on the tube for some time and only flowed off the tube at irregular intervals.

In the derivation of an equation to fit the data a plot (Figure 10) of

$$h\left(\frac{\mu^2}{(k_{av.})^3\,(\rho_{av.})^2\,g}\right)^{1/3}$$

against Q_s/Q on logarithmic paper gave a straight line for each system. The intercepts of these lines at a constant



value of $Q_s/Q=0.60$ were plotted against the Prandtl number, $C_{pav.}/k_{av.}$. This would not line up the intercept values. However, it was found that multiplying the Prandtl number by the density to the 0.7 power divided by the latent heat of vaporization for the mixture, $\rho^{0.7}{}_{av.}/\lambda_{av.}$ (Figure 11), brought the intercept values into line.

The plot of

$$h\left(\frac{\mu^2}{k^3{}_{av.}\,\rho^2{}_{av.}\,g}\right)^{1/3}\Big/\left(\frac{C_{pav.}\,\mu\,\rho^{0.7}}{k_{av.}\,\lambda_{av.}}\right)^{2.38}$$

against Q_s/Q (Figure 12) showed that all values for the benzene, toluene, and trichloroethylene systems lay on a single straight line, but the values for the heptane system lay on another straight line of a different slope.

The equation finally derived (Figure 13) is empirical and not dimensionally consistent, but it does correlate the present data and those of Kirkbride. The final form of the equation, plotted as a line on Figure 13 is:

$$h\left(\frac{\mu^2}{k^3{}_{av.}\,\rho^2{}_{av.}\,g}\right)^{1/3} = 1.28\left(\frac{C_{pav.}\,\mu\,\rho^{0.7}{}_{av.}}{k_{av.}\,\lambda_{av.}}\right)^{2.38}\frac{Q_s}{Q}^{-3.28}$$

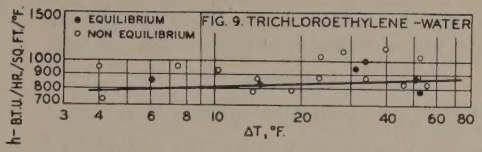
The equation holds over a considerable range of Q_s/Q but should not hold at the limits of Q_s/Q because the coefficient h is for the condensation of mixed vapors, and at either limit only a pure vapor exists. The lower limit of Q_s/Q was almost reached by Kirkbride. The upper limit, however, has not been reached.

Conclusions

Kirkbride's equation was based on the Nusselt equation for the individual films. However, the data collected here show that the Nusselt equation cannot be properly applied to this type of condensation; therefore, any modification of the Nusselt equation will also be in error.

Although the equation offered is empirical and is not dimensionally consistent, it does fit the data better than the Kirkbride equation, and the writers' equation also checks the data presented by Kirkbride.

A strictly theoretical attack on this problem cannot be made at the present. However, when the thermal and physi-



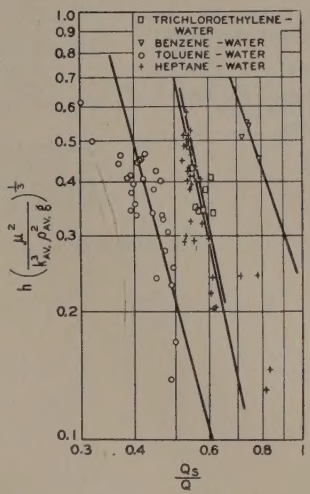


FIGURE 10. PARTIAL CORRELATION OF HEAT TRANSFER DATA
A different straight is obtained for each system.

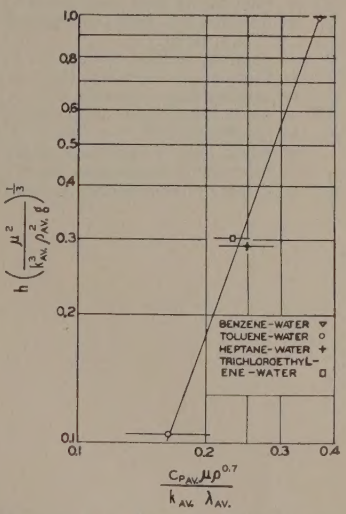


FIGURE 11. PARTIAL CORRELATION OF HEAT TRANSFER DATA

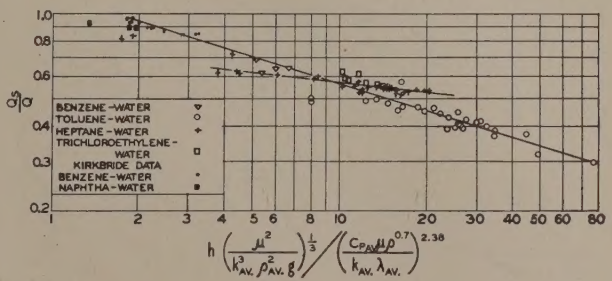


FIGURE 12. PARTIAL CORRELATION OF HEAT TRANSFER DATA

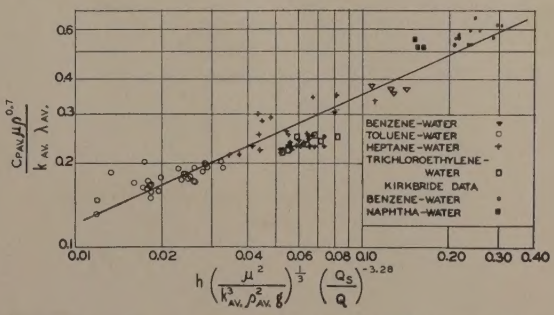


FIGURE 13. FINAL CORRELATION OF HEAT TRANSFER DATA FOR MIXED VAPORS

cal properties of a mixture of immiscible liquids can be predicted, such a theoretical solution may be possible. More information is also needed on the surface properties of metals.

Nomenclature

h = coefficient of heat transfer for mixture, B. t. u./(hr.)(° F.)(sq. ft.)
h_w = coefficient of heat transfer for water, B. t. u./(hr.)(° F.)(sq. ft.)
h_s = coefficient of heat transfer for second component, B. t. u./(hr.)(° F.)(sq. ft.)
Q_w = quantity of heat transferred by water, B. t. u./hr.
Q_s = quantity of heat transferred by second component, B. t. u./hr.
Q = quantity of heat transferred by mixture, B. t. u./hr.
k = thermal conductivity, (B. t. u.)(ft.)/(hr.)(° F.)(sq. ft.)
g = acceleration of gravity, 4.18×10^8 ft./(hr.)(hr.)
ΔT = mean temperature drop through the film, ° F.
C_p = specific heat, B. t. u./(lb.)(° F.)
λ = latent heat of vaporization, B. t. u./lb.
μ = viscosity of condensate, lb./(ft.)(hr.)
ρ = density of condensate, lb./cu. ft.

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